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The Effect of Injury Simulating Hail Damage to Soybeans

By R. R. Kalton, C. R. Weber and J. C. Eldredge

AGRICULTURAL EXPERIMENT STATION
IOWA STATE COLLEGE OF AGRICULTURE
AND MECHANIC ARTS

FARM CROPS SUBSECTION
AGRONOMY SECTION

UNITED STATES REGIONAL SOYBEAN LABORATORY

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BUREAU OF PLANT INDUSTRY, SOILS AND AGRICULTURAL ENGINEERING
AGRICULTURAL RESEARCH ADMINISTRATION
UNITED STATES DEPARTMENT OF AGRICULTURE

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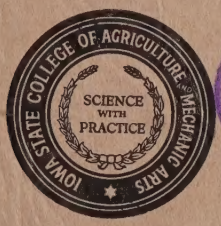

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SUMMARY

1. Each year during a 4-year period light, medium and heavy simulated hail damage was inflicted on replicated plots of soybeans at different stages of development. Two methods of inflicting injury, beating and clipping, were compared for 1 year with a difference of only 1/10 bushel between them. In one year two varieties (Lincoln and Richland) were used. They responded in a similar manner to injury.

2. Yields were consistently reduced most when simulated hail damage was inflicted at about the time seed began developing in the lower pods. Average decreases in yield at that stage were 27, 50 and 77 percent for light, medium and heavy damage, respectively. Yields were reduced least when the plants injured were 6 to 12 inches tall and had from two to five trifoliate leaves unrolled.

3. Simulated hail injuries before and during blooming delayed maturity approximately 3 days for medium and 8 days for heavy damage. All degrees of damage after the "green bean" stage hastened maturity several days. Plant height was reduced most when injury was inflicted during blooming. Heavy damage during that period decreased height approximately 40 percent. Medium and heavy damage while seed was developing lowered its quality and markedly reduced its size. Light damage slightly decreased seed size at the same stages.

4. In a 1-year test weed growth was appreciably increased on plots which were not hand-weeded only when all plants were cut off above the cotyledons at stage 1 (plants were 4 to 5 inches tall with one trifoliate leaf completely unrolled). The added weed growth only slightly decreased the yield as compared with the hand-weeded plots.

5. Although protein percentage of the seed was not appreciably affected by the simulated hail injuries, oil percentage was consistently decreased by heavy damage before the pods began to yellow. To a lesser extent, medium damage showed the same tendency. The greatest decrease in oil percentage of the seed was 2.4 percent, which resulted from heavy damage at the time the beans in the lower pods were approaching the "green bean" stage. All degrees of damage during the period of pod formation and early seed development tended to increase the iodine number of the oil with Richland, but this tendency was apparent only following medium and heavy damage with Lincoln.

6. For 2 years stands of Richland were reduced by

cutting off 25, 50 and 75 percent of the plants at ground level and at one-half their height at five stages of growth. Reductions in yield became progressively greater from stand removal as the plants developed. Yields were decreased most when beans in the pods were approaching the "green bean" stage and the lower leaves had started to yellow. Removal of 25, 50 and 75 percent of the plants at the ground level at that stage reduced the yield an average of 16, 43 and 73 percent, respectively. Before blooming 25 and 50 percent stand reduction at ground level and at half height reduced yields about the same. After blooming, cutting off the plants at ground level consistently reduced yields more than cutting them off at half height. At all stages of growth cutting off 75 percent of the plants at ground level caused greater reduction in yield than cutting at half height.

7. Stand removal had little effect on plant height and date of maturity. Reducing the stand 50 and 75 percent just before and during blooming slightly decreased plant height.

8. In defoliation tests for 2 years 10, 25, 50, 75 and 100 percent of the leaves were removed at five stages of plant development from replicated plots of Richland. Removing 10 to 75 percent of the leaves before blooming reduced the yield only slightly. When all leaves were removed during the same period, the average yield decreased 22 percent. Yields were reduced most in every instance when leaves were removed at the time beans were beginning to develop in the lower pods. Decreases in yield at that stage were 8, 13, 18, 36 and 83 percent for 10, 25, 50, 75 and 100 percent defoliation, respectively.

9. Maturity was delayed 4 to 5 days by 100 percent defoliation before and during blooming and was hastened several days by 75 and 100 percent leaf removal after the plants reached the "green bean" stage. Lesser amounts of defoliation had no significant effect on maturity. Plant height was markedly decreased only by total defoliation before and during blooming. The greatest decrease, 19 percent, occurred at full bloom stage. Poorer seed quality resulted only with 100 percent defoliation during the period of seed development. Seed size was decreased approximately 10 and 22 percent by 75 and 100 percent leaf removal, respectively, at the same stages.

10. Leaf removal had no appreciable effect on protein percentage of the seed. Oil percentage was decreased an average of 1.7 percent by 100 percent defoliation during

the period of seed development. In both years iodine number of the oil was increased by 50, 75 and 100 percent leaf removal during the stage of beginning seed development. The same treatments in the second year caused an increase in iodine number at the "green bean" stage.

11. Lodging in these studies was not considered comparable to that following actual hail. Simulated damage tended to decrease the amount of lodging, while actual hailstorms generally cause considerable increases in lodging due to accompanying winds.

12. A 1-year test on simulated seed shattering indicated that seed size is important in estimating shatter losses from hail.

The Effect of Injury Simulating Hail Damage to Soybeans [1]

By R. R. Kalton, C. R. Weber and J. C. Eldredge[2]

Hail has damaged soybeans in Iowa rather frequently in recent years. Although no figures are available on the extent of these losses to soybeans alone, the annual estimated losses from hail damage to all crops in Iowa from 1936 to 1946 may show their probable significance. These losses, shown in table 1, were compiled from township assessors' reports. Crop losses due to hail damage apparently were considerably above average from 1942 to 1946. During this same period soybean acreage and production reached an all-time peak in Iowa (table 2).

The expanded acreage and production of soybeans together with the increased incidence of hail has resulted in a large increase in the hail insurance written on this crop. Little was known regarding the evaluation of hail losses to soybeans when these experiments were initiated. Neither farmers nor hail adjustors knew the recovery to expect after soybean crops were damaged by hail at different stages of plant development. To provide this information was the principal objective of the investigations reported in this bulletin.

Hailstorms cause various kinds and degrees of injury to soybean plants. In some instances only a few leaves are torn off or shredded and stems slightly bruised. In other cases practically all leaves may be removed and many plants may be broken down or cut off. In the latter part of the season pods may be bruised or knocked off in addition to leaf and stem injuries. Terminal buds may be cut off or damaged at different stages of development. The types of possible hail injury fall naturally into several different

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TABLE 1. ANNUAL ESTIMATED LOSSES FROM HAIL DAMAGE TO ALL CROPS IN IOWA FROM 1936-46.*

Year	Estimated crop losses from hail damage	Number of Iowa counties reporting hail damage
1936	$ 2,898,790	89
1937	1,890,235	87
1938	1,599,187	94
1939	1,107,816	83
1940	1,637,645	80
1941	2,649,434	91
1942	4,184,133	95
1943	13,232,824	97
1944	10,000,175	95
1945	6,839,576	96
1946	7,464,212	95
20-year average 1923-42	3,092,366	

*Taken from the Annual Iowa Yearbooks of Agriculture issued by the Iowa State Department of Agriculture and published by the State of Iowa, Des Moines, Iowa.

classes as follows: (1) leaf shredding or removal, (2) stem damage involving bruising, breakage or removal, and (3) pod bruising or removal. Any one or all of these types of hail damage may occur during the growing season. After plants are mature, the main type of damage is shattering.

Hailstorms cannot be manufactured at will nor can the accompanying weather conditions be duplicated. We were able, however, to inflict different degrees of damage to soybean plants that approximated a combination of the various types of injury resulting from actual hail. We studied separately different percentages of leaf and stem removal at different stages of plant development and determined their effect on yield and chemical composition of the seed and on other agronomic characters. The results obtained in these simulated hail tests and their possible relationships to actual hail damage are presented and discussed herein.

TABLE 2. ANNUAL ACREAGE AND PRODUCTION OF SOYBEANS HARVESTED FOR BEANS IN IOWA FROM 1936-46.*

Year	Acres	Production in bushels
1936	174,452	2,408,847
1937	219,120	4,050,229
1938	305,943	6,462,314
1939	539,365	11,095,972
1940	702,720	13,968,336
1941	932,609	15,799 604
1942	1,799,757	34,723,807
1943	1,857,744	35,708,293
1944	1,884,090	37,939,251
1945	1,883,619	34,358,795
1946	1,539,181	35,119,653

*Taken from the Annual Iowa Yearbooks of Agriculture issued by the Iowa State Department of Agriculture and published by the State of Iowa, Des Moines, Iowa.

REVIEW OF PERTINENT LITERATURE

Simulated hail studies have been conducted with several different crops. The majority reported have been with corn and the small grains. Eldredge (4) reviewed hail studies with corn previous to 1935 and reported the results of a 5-year study on the effect of injury imitating hail damage on development of the corn plant. He found that the greatest reduction in yield of grain occurred when damage (leaf stripping, leaf shredding and stalk bruising) was inflicted during the tasseling period. Similar results were obtained by Kiesselbach and Lyness (11). In a defoliation experiment with kaoliang, Li and Liu (13) removed all leaves at various stages of growth and also obtained the greatest reduction in seed yield during the blooming period. Complete defoliation when the kernels were in the dough stage caused insignificant decreases in yield.

The effect of several types of injury at weekly intervals during the growing season on yields of wheat, oats and barley was measured by Eldredge (5). He found that damage inflicted during the vegetative stages resulted in less reduction in yield than damage at heading time, with the reductions being progressively less at weekly intervals before heading. In an experiment designed to measure the the effect of grasshopper damage, White (16) completely defoliated wheat plots at a number of stages of plant development. Yields were reduced most when all leaves were removed from heading to soft dough stage. Complete defoliation during the two weeks just prior to maturity did not affect yields. Bushel weight and plant height were reduced most by defoliation when heads were emerging.

Klages (12) observed that the effects of simulated hail damage to flax were similar to those with small grains. In his studies, recovery from damage was greatest when plants were in the early stages of growth. Leaf removal was most detrimental to yield at the budding and flowering stages. The results indicated that mechanical injuries to the stems caused considerably more reduction in yield than removal of leaves.

Recently, Hawthorn (9) reported the results of a 2-year study of defoliation in onions. In that study (1) one-half the foliage and (2) all the foliage were removed from rows of two varieties of onions. The treatments extended over a period ranging 1 to 11 weeks before harvest in each of the two years 1943 and 1944. The most serious loss in yield resulted in both varieties when foliage was removed during

the beginning of bulb formation. Losses at that time varied from 84 to 100 percent.

Very little information has been published pertaining directly to the effect of injury in imitation of hail damage to soybeans. Dungan (2) measured the effect of removing all leaves from spaced soybean plants cut off 1 foot above the ground at several different times during the period of pod formation and bean development. When compared with paired undamaged plants, this type of injury caused an average loss in yield of more than 95 percent. In another part of the same test removal of approximately 50 percent of the leaves at the same stages of development caused an average loss in yield of 22 percent. Yields were reduced most when half the leaves were removed at the time the pods were approximately 1⅓ inches long and nearly flat. The least effect on yield occurred when one-half the leaves were removed at the time the pods were full length and the beans approximately one-half grown. This study was conducted only during the period of pod and bean development.

In another experiment Dungan (3) damaged soybean plants in several ways at the following four stages: (1) first trifoliate leaf, (2) vegetative, (3) flowering and (4) seed one-half developed. At all stages when 100 percent of the leaves and cotyledons or 100 percent of the leaves and stems above the cotyledons were removed, no seed was produced. The removal of all leaves caused only slight reductions in seed yield at the first stage but much larger reductions at the last three stages. Removal of the upper leaves and parts of the stems, as the plants developed, resulted in progressively greater losses in yield. In every case the treatments delayed maturity in comparison with the checks. As this study was conducted in the greenhouse, the results may not be strictly comparable to field conditions.

In another simulated hail study with soybeans Fuelleman (6) removed three different percentages of leaves (30, 50 and 75 percent) from replicated rows of the Richland variety at each of seven dates throughout the growing season. The 75 percent defoliation treatment also included bruising and breakage of stems. The 30 and 50 percent defoliation treatments before blooming reduced the yield little, whereas 75 percent defoliation materially reduced the yield. All rates of defoliation when inflicted at the period of pod and seed formation brought about severe reductions in yield.

A defoliation experiment with soybeans was conducted in North Carolina by Gibson, *et al.* (8). In this investiga-

tion varying quantities of leaves were removed from two varieties at 10-, 20- and 30-day intervals during the growing season. Reductions in seed yield were progressively greater as the amount and frequency of defoliation increased. Practically no seed was produced by one of the varieties (Biloxi) when completely defoliated at each of the three intervals. A small amount of seed was produced by the second variety (Tokyo) at the 20- and 30-day intervals of 100 percent defoliation. The smallest decrease in yield resulted when all but six leaves were removed from each plant at 30-day intervals.

The experiments thus far reviewed were related only to the effect of injury on yield and maturity of soybean plants. Garner, *et al.* (7) noted that other agronomic characters also might be affected by varying degrees and kinds of injury. They studied the effect of partial defoliation and removal of blossoms and young seed pods on seed size, oil content of the seed, plant height and seed yield. Partial defoliation consisted of removal of 50 to 60 percent of the leaves several times just before and after blooming. In all cases this treatment decidedly reduced plant height and total yield of seed but only slightly reduced seed size. Oil percentage of the seed, on the other hand, was increased by the injury. In another phase of the study a portion of the blossoms and young pods were removed shortly after blooming. This treatment also reduced the yield. The beans that developed in this case, however, were considerably larger than those on undamaged plants. Oil percentage of the seed was unaffected by this type of injury.

In addition to leaf and pod injuries, hail may also reduce the stand. Generally, with soybeans planted in rows at the recommended rate (approximately a bushel per acre for 36- to 42-inch rows) a stand of 9 to 12 plants per foot results. Wiggans (17) and Probst (15) found that stand could vary from as few as four to five up to as many as 20 to 25 plants per linear foot of row without noticeable effect on yields when weeds were eliminated. The thicker stands, however, resulted in delayed maturity and more lodging. Results of many rate-of-seeding tests by a number of experiment stations also have indicated that soybean varieties can adjust themselves to a relatively wide range in stand without altering yield appreciably.

Injuries to leaves and stems resulting from hail may be confused with certain soybean diseases. This is especially true for bacterial blight, bacterial pustule, Alternaria leaf spot and frogeye disease, which are found on the leaves,

and for pod and stem blight, which is found on the stems and pods. Consequently, the ability to distinguish hail injury from disease is desirable. Johnson and Koehler (10) discussed and illustrated many of the important soybean diseases in the United States in 1943. Grasshopper injury to soybeans also might be confused with light hail damage, as both result in a "shot-hole" appearance of the leaves.

EXPERIMENTAL METHODS

Investigations relative to the effect of injury simulating hail damage to soybeans were initiated at the Iowa Station in 1943 and continued through 1946. The study was divided into four different phases as follows:

Simulated hail tests	(1943 through 1946)
Defoliation tests	(1945 and 1946)
Stand reduction tests	(1945 and 1946)
Shatter test	(1946)

In the simulated hail tests an attempt was made to simulate actual hail injury as closely as possible. This was done by using instruments to remove certain amounts of the leaves and to bruise and break the stems at various stages of plant development. In the defoliation and stand reduction tests specific amounts of leaves and stems, respectively, were removed at several dates during the growing season. The shatter test was concerned with estimating shatter losses on the basis of seed size results for several previous years.

TABLE 3. DESCRIPTION OF SIMULATED HAIL DAMAGE INFLICTED AT EACH STAGE OF GROWTH. 1943 THROUGH 1946.

Check—No damage.

Light damage

Each stage of growth—average of 25-30 percent of leaves removed and 1-2 percent of plants broken. Minor stem bruising incidental to leaf removal.
First through seventh stage of growth—2-5 percent of terminal buds removed.
Seventh through tenth stage of growth—1-3 percent of pods removed.

Medium damage

Each stage of growth—average of 55-60 percent of leaves removed and 4-7 percent of plants broken.
First through seventh stage of growth—10-15 percent of terminal buds removed.
Fourth through tenth stage of growth—plants bruised with one blow between a lath and board.
Seventh through tenth stage of growth—3-7 percent of pods removed.

Heavy damage

First stage of growth—all plants cut off just above the cotyledons.
Second through tenth stage of growth—average of 80-90 percent of leaves removed.
Second through seventh stage of growth—10-15 percent of plants broken and 50-60 percent of terminal buds removed.
Seventh through tenth stage of growth—8-12 percent of pods removed.
Eighth through tenth stage of growth—6-10 percent of plants broken.
Fourth through tenth stage of growth—plants bruised with two blows between a lath and board.

The methods and procedures used in each of these tests are presented and discussed in succeeding sections.

All investigations reported herein were conducted at the Agronomy Farm, Ames, Iowa. The plots were planted with small nursery planters at a rate of approximately 1 bushel per acre in each year, except 1945. In that year a slightly heavier rate was seeded resulting in a stand of 13 to 14 plants per foot. The stand in 1943, 1944 and 1946 was about 8 to 10 plants per foot.

In 1943, three degrees of injury simulating hail damage were inflicted on small replicated plots of Richland soybeans at five different stages of development. A description of the damage that resulted is found in table 3. For simplicity, the three degrees of injury were designated "light," "medium" and "heavy" damage. The five stages of plant development at which damage was inflicted are described in table 4 as stages 1, 3, 5, 7 and 9; photographs of soybean plants representing each are shown in figs. 1 to 5, inclusive.

TABLE 4. STAGES OF GROWTH AT WHICH SIMULATED HAIL INJURY WAS INFLICTED. 1943 THROUGH 1946.

Stage of growth	Average date	Average height (inches)	Ceneral description of plant development
1	June 18	4-6	First trifoliate leaf completely unrolled, second trifoliate leaf in bud stage of unrolling.
2	June 28	7-9	Three trifoliate leaves comp'etely unrolled, fourth one beginning to unroll. Some cotyledons dropped.
3	July 8	12-14	Five to six trifoliate leaves unrolled. One to 5 percent of plants flowering.
4	July 15	15-18	Seven to eight trifoliate leaves unrolled. Some stem branching. Forty to 60 percent of plants flowering with one to four flowers per plant.
5	July 21	21-24	Nine to ten trifoliate leaves unrolled. More stem branching evident. Full bloom stage with withered flowers in lower leaf axils.
6	Aug. 2	26-28	Pods in lower half of plants well formed and up to ½ inch long. Practically through blooming although a few flowers still in evidence in tops of plants.
7	Aug. 12	31-33	Pods plainly evident in tops of plants. Lower pods nearly full length with beans developing in them. Flowering ceased.
8	Aug. 26	33-35	Pods in top of plants full length. Pods in lower half of plants containing beans approaching "green bean" stage. No yellowing of leaves.
9	Sept. 4	33-36	Bottom leaves on plants beginning to yellow. Top pods almost fully developed with beans approaching "green bean" stage.
10	Sept. 13	34-37	Leaves 30 to 50 percent yellow with a few falling. Lower pods yellowing.

Fig. 1. Stage of growth 1. First trifoliate leaf completely unrolled: second trifoliate leaf unrolling.

Fig. 2. Stage of growth 3. Five to six trifoliate leaves unrolled; few plants flowering.

Fig. 3. Stage of growth 5. Nine to ten trifoliate leaves unrolled; full bloom stage.

Fig. 4. Stage of growth 7. Pods plainly evident in tops of plants. Lower pods nearly full length with beans developing in them. Flowering ceased.

Fig. 5. Stage of growth 9. Bottom leaves on plants beginning to yellow. Top pods almost fully developed and with beans approaching "green bean" stage.

Plants were damaged by two different methods. In one method various portions of leaves and stems were clipped off with shears. In the second method, hereafter referred to as the shredding or beating method, an instrument made by mounting several heavy wire hooks on a paddle-like board was used to remove leaves and stems by an upward stroke. Either of these methods was satisfactory for obtaining the desired degree of damage.

The Richland variety was used in the 1943 hail study because of its lodging resistance and early maturity. These attributes made it especially adapted to these experiments. The experimental plots consisted of 15-foot rows spaced 36 inches apart. In subsequent years, 1944 through 1946, inclusive, 16-foot rows spaced 42 inches apart were used to reduce competition between rows treated differently. In all cases each row was damaged only once. A 4 x 4 latin square with the degrees of damage (check, light, medium and heavy) as whole plots and the five stages of growth as subplots constituted the experimental design.

The effects produced by the two methods of inflicting damage in 1943 were very similar. Consequently, only the shredding (beating) method of inflicting injury was used in 1944 and in subsequent years. The 1944 test was enlarged by including five additional stages of plant develop-

Fig. 6. Injury resulting from the infliction of light damage at full b'oom stage, stage of growth 5. Photo taken July 17, 1946.

Fig. 7. Injury resulting from the infliction of medium damage at full bloom stage, stage of growth 5. Undamaged row in background. Photo taken July 17, 1946.

Fig. 8. Injury resulting from the infliction of heavy damage at full bloom stage, stage of growth 5. Note recovery on row in background. It was inflicted with heavy damage at stage of growth 8. Photo was taken July 17, 1946.

ment. These stages, namely, 2, 4, 6, 8 and 10, are described in table 4.

The possibility that soybean varieties might react differently to the effects of simulated hail injury prompted the inclusion of a second variety, Lincoln, in the 1944 test. Lincoln differs considerably from Richland in growth habit. It lodges and branches more and matures a week later than Richland. The addition of Lincoln to the study necessitated a modification in the experimental design. A sub-subplot feature was included with varieties constituting the subplots and stages of growth the sub-subplots. The whole plots of the 4 x 4 latin square remained the same. On the basis of results in 1943 and 1944, the studies were continued in the two succeeding years with only the Richland variety. The stages of growth, degrees of damage, plot size and experimental design remained the same. The studies were terminated in 1946.

Rows showing different degrees of damage at several stages of growth were photographed in 1946. Figures 6, 7 and 8 illustrate the damage resulting from infliction of three degrees of simulated hail injury (light, medium and heavy) at full bloom stage (stage of growth 5). Several plants in the "green bean" stage damaged by actual hail are shown in fig. 9. Figure 10 shows a row inflicted with heavy damage at stage of growth 9. The amount and type of injury resulting from actual hail and simulated hail appear to be similar in these two photographs.

The effects of injury simulating hail damage to soybeans were measured by the following plant and seed characteristics: seed yield, date of maturity, plant height, lodging, seed quality, seed size, protein and oil percentage of the seed and iodine number of the oil. The methods used in determining each of these characters were as follows:

Seed yield—air-dry plot yields calculated in bushels per acre.

Date of maturity—expressed as the calendar date when 90-100 percent of the pods had turned brown and most leaves had fallen from the plants.

Plant height—average height in inches from ground level to the highest point on the mature plants.

Lodging—scored on the scale of 1 (nearly erect) to 5 (all plants nearly prostrate).

Seed quality—scored on a scale ranging from 1 (very good) to 5 (very poor), considering seed development, seed coat defectiveness, and color.

Seed size—expressed as weight in grams per 100 seeds.

Fig. 9. Plants severely damaged by actual hail at the "green bean" stage. Collected near Belmond, Iowa, on Sept. 5, 1946.

Fig. 10. Injury resulting from the infliction of heavy damage when beans in top pods were approaching the "green bean" stage, stage of growth 9. Photo taken Sept. 2, 1946.

Protein and oil percentage—expressed as percentage on a dry weight basis.

Iodine number of oil—a measure of drying quality of the oil determined by refractive index on a colorimetric scale.

Seed quality, size and chemical composition were not taken in the 1943 test.

One of the characteristic features of many hailstorms is that they break or cut off various portions of the soybean plants. Therefore, we studied separately the effect of different amounts of stand removal at several stages of plant development on seed yield and other agronomic characters. The stand reduction test was initiated in 1945. In this test three percentages of stand, namely, 25, 50 and 75 percent, were removed at two different heights, one at ground level, the other at one-half the height of the plants. Each of these percentages of stand reduction was carried out at five stages of plant development corresponding to stages 1, 3, 5, 7 and 9, as described in table 4. The stand was reduced at each stage by cutting off the desired percentages of the plants at each height with a grass clipper. The appearance of rows in which 75 percent of the stand was removed at the two heights is shown in figs. 11 and 12. This same test was repeated in 1946.

In the stand reduction tests in 1945 and 1946 plots of the

Fig. 11. Part of a row in which 75 percent of the plants were cut off at ground level at full bloom stage, stage of growth 5. Check row in background. Photo taken July 17, 1946.

Fig. 12. Part of a row in which 75 percent of the plants were cut off at one-half their height at full bloom stage, stage of growth 5. Note stem stumps in the center of the picture. Photo taken July 17, 1946.

Richland variety were planted in 16-foot rows spaced 42 inches apart. A 4 x 4 latin square with a double split plot was used as the experimental design. The percentages of stand reduction constituted the whole plots, heights were the subplots, and stages of growth the sub-subplots. The effect of stand reduction on seed yield, date of maturity, plant height and lodging was determined in the same manner as in the simulated hail tests.

Hailstorms universally strip the leaves from soybean plants in varying amounts. For that reason a defoliation test in which certain percentages of leaves were removed from the plants also was conducted in 1945 and 1946. Five different percentages (10, 25, 50, 75 and 100) of leaves were removed at five stages of plant development during the season. The stages of growth corresponded to those described as 1, 3, 5, 7 and 9 in table 4. Leaves were removed by pinching off the desired percentage from each plant at a point just below the attachment of the leaf to the petiole (leaf stalk). By so doing, no other injury resulted to the plant. Figure 13 shows a row in which 100 percent of the leaves were removed at stage of growth 5 (full bloom stage) in the manner just described.

The exacting job of defoliation was conducted on rows 8 feet in length and spaced 42 inches apart so that all de-

Fig. 13. A row of Richland soybeans from which 100 percent of the leaves were removed when the plants were at full bloom stage, stage of growth 5. Note recovery by regeneration of new leaves of row at right from which 100 percent of the leaves were removed at stage of growth 3, and the row at left from which 100 percent of the leaves were removed at stage of growth 1. Photo taken July 17, 1946.

grees of defoliation at any one stage of growth could be removed the same day. A randomized split-plot arrangement with percentages of defoliation as the whole plots and stages of growth as the subplots constituted the experimental design. Each subplot was replicated four times. The effect of defoliation on agronomic characters and on chemical composition of the seed was determined as in the simulated hail tests.

Although most hailstorms in Iowa come during the growing season, a few occur in late September and in October. At that time, the majority of soybean fields are mature, and seed shattering is the primary result of hail. In order to obtain some information on estimating such losses, a small test simulating seed shattering was conducted in the fall of 1946. In this test the average weight in grams per hundred seeds of Richland for the several previous years was used to estimate the number of seeds required to obtain varying amounts of simulated shatter loss in bushels per acre. In all, 10 levels of shatter loss were estimated, ranging from no loss to a loss of 27 bushels per acre, with 3-bushel intervals between each level. The estimated number of beans then were removed from 8-foot rows of Richland spaced 42 inches apart. Four replications were used for each level of estimated shatter loss. The amount of beans removed was then calculated in bushels per acre and compared with the expected losses.

EXPERIMENTAL RESULTS

These investigations were divided into four distinct phases, and the results for each are presented separately in the following sections. Major emphasis of the discussion is placed on yield of seed, as it is the primary consideration in adjusting hail losses. Data for other agronomic characters and for chemical composition of the seed are presented separately as long-time averages.

For brevity stages of growth usually are referred to by the numerical stage or stages. Calendar dates are omitted, since varietal and seasonal effects may have considerable influence on the time plants reach any particular stage of development. Descriptions given in table 4 should be kept in mind, as a stage of growth usually can be ascertained with reasonable accuracy for any variety of soybeans in any season. The effect of simulated hail injury to soybeans depends not only upon the amount and kind of damage but also upon the stage of development of the plants when damage occurs.

SIMULATED HAIL TESTS
(1943 through 1946)

SEED YIELD

Information was sparse concerning the recovery of soybeans from hail injury when these investigations were initiated in 1943. It was necessary, therefore, to design the experiments so as to gain information on both the effect of simulated hail damage and the methods of inflicting injury. Two methods of inflicting injury were compared in the 1943 test—beating and clipping. These methods have already been described. Yields resulting from these methods appear in table 5 and their analysis of variance in table 6. The two methods gave similar reductions in yield, with a difference of only 1/10 bushel. The yield discrepancies between the methods at stage 9 with medium and heavy damage were the result of greater pod removal with beating than with clipping.

In the 1944 test only the beating method of inflicting injury was used, but a second variety and five more stages of growth were added. The yields of the Lincoln variety in 1944 are shown in table 7. Yields for the Richland va-

TABLE 5. EFFECT OF THREE DEGREES OF SIMULATED HAIL DAMAGE INFLICTED BY TWO METHODS AT FIVE STAGES OF GROWTH ON YIELD OF SEED IN SOYBEANS. 1943.

Degree of damage	Stage of growth when damage inflicted	Beating		Clipping	
		Yield Bu./A	Percent of check	Yield Bu./A	Percent of check
Check (no damage)		33.3		33.3	
Light damage	1	32.1	96	31.3	94
	3	32.3	97	31.2	94
	5	27.9	84	26.5	80
	7	21.2	64	21.8	65
	9	26.8	80	28.0	84
Mean		28.1	84	27.7	83
Medium damage	1	32.3	97	32.1	96
	3	32.2	97	33.0	99
	5	27.9	84	27.6	83
	7	20.3	61	19.5	59
	9	26.2	79	30.2	91
Mean		27.8	83	28.5	86
Heavy damage	1	31.2	94	24.7	74
	3	28.4	85	25.9	78
	5	22.7	68	22.0	66
	7	15.7	47	14.2	43
	9	18.4	55	26.8	80
Mean		23.3	70	22.7	68
Grand mean		26.4		26.3	

TABLE 6. ANALYSIS OF VARIANCE OF YIELDS FOR SIMULATED HAIL TEST. 1943.

Source of variation	D. F.	Mean square
Whole plot—including checks on a sub-subplot basis:		
Rows	3	16.14
Columns	3	22.34
Degrees of damage	3	715.12
Error (a)	6	12.57
Subplot -eliminating checks on a sub-subplot basis:		
Stages of growth	4	556.95
Stages of growth x degrees of damage	8	3.34
Error (b)	36	4.81
Sub-subplot -eliminating checks:		
Methods of damage	1	.11
Methods x stages of growth	4	43.30
Methods x degrees of damage	2	4.64
Methods x stages x degrees of damage	8	13.49
Error (c)	45	5.67

TABLE 7. EFFECT OF THREE DEGREES OF SIMULATED HAIL DAMAGE AT 10 STAGES OF GROWTH ON YIELD OF SEED OF LINCOLN SOYBEANS. 1944.

Stage of growth when damage inflicted	Light damage		Medium damage		Heavy damage	
	Yield Bu./A	Percent of check	Yield Bu./A	Percent of check	Yield Bu./A	Percent of check
1	33.7	82	34.4	84	35.6	87
2	37.6	91	46.6	113	28.9	70
3	36.1	88	37.0	90	27.4	67
4	36.7	89	25.8	63	18.9	46
5	38.1	93	30.7	75	23.5	57
6	34 6	84	26.3	64	13.1	32
7	28.6	70	20.6	50	6.9	17
8	30.4	74	21.1	51	10.2	25
9	30.0	73	23.7	58	16.8	41
10	30.3	74	23.7	58	22.2	54
Mean	33.6	82	29.0	71	20.3	49

Average yield of check (no damage) in bushels per acre = 41.1.

riety in 1944, 1945 and 1946 are shown in table 8. Similar degrees of damage and stages of growth were used in each of three years. Analyses of variance of yields for the 1944 test with two varieties, and for the 1944 to 1946 tests with Richland, appear in tables 9 and 10, respectively.

Not all of the yield results obtained will be discussed in detail here, but the more significant features will be pointed out. In all tests noticeable decreases in yield resulted from different degrees of damage. On the average the decrease in yield for each degree of damage was similar

TABLE 8. EFFECT OF THREE DEGREES OF SIMULATED HAIL DAMAGE AT 10 STAGES OF GROWTH ON YIELD OF SEED OF RICHLAND SOYBEANS.

Degree of damage	Stage of growth when damage inflicted	1944		1945		1946		Average 1944 to 1946	
		Yield Bu./A	Percent of check	Yield Bu./A	Percent of check	Yield Bu./A	Percent of check	Yield Bu./A	Percent of check
Check (no damage)		36.9		30.0		33.2		33.4	
Light damage	1	27.9	76	27.0	90	31.3	94	28.7	86
	2	33.5	91	27.5	92	31.3	94	30.8	92
	3	32.0	87	26.6	89	32.7	98	30.4	91
	4	29.5	80	27.6	92	29.5	89	28.8	86
	5	31.1	84	26.0	87	28.2	85	28.4	85
	6	25.0	68	23.8	79	28.0	84	25.6	77
	7	22.0	60	24.1	80	27.4	83	24.5	73
	8	26.1	71	25.8	86	25.7	77	25.8	77
	9	27.0	73	26.7	89	25.6	77	26.4	79
	10	29.8	81	27.7	92	30.1	91	29.2	87
Mean		28.4	77	26.3	88	29.0	87	27.9	84
Medium damage	1	30.2	82	25.2	84	28.9	87	28.1	84
	2	37.7	102	24.8	83	32.4	98	31.6	95
	3	33.3	90	23.9	80	27.8	84	28.3	85
	4	29.1	79	19.8	66	25.2	76	24.7	74
	5	30.9	84	19.6	65	22.8	69	24.4	73
	6	21.4	58	15.9	53	20.7	62	19.3	58
	7	18.5	50	15.9	53	15.7	47	16.7	50
	8	18.7	51	17.5	58	17.8	54	18.0	54
	9	23.2	63	21.8	73	19.9	60	21.6	65
	10	28.8	78	24.2	81	28.1	85	27.0	81
Mean		27.2	74	20.8	69	23.9	72	24.0	72
Heavy damage	1	28.1	76	17.0	57	18.7	56	21.2	63
	2	29.8	81	21.0	70	26.6	80	25.8	77
	3	23.4	63	22.3	74	25.1	76	23.6	71
	4	18.8	52	17.8	59	20.6	62	19.0	57
	5	22.2	60	15.8	53	17.2	52	18.4	55
	6	10.9	30	10.0	33	14.8	45	11.9	36
	7	6.1	17	8.3	28	8.8	27	7.7	23
	8	10.4	28	11.0	37	9.9	30	10.4	31
	9	21.6	59	18.3	61	14.9	45	18.3	55
	10	28.0	76	22.6	75	22.2	67	24.3	73
Mean		19.9	54	16.4	55	17.9	54	18.1	54

in all years, irrespective of the method of damage or variety. Medium damage did not cause a greater reduction in yield than light damage in 1943, even though there were visual differences in appearance between the respective degrees of damage. From 1944 through 1946, however, medium damage decreased the yield more than light damage, with the reductions being similar each year. Heavy damage caused the largest reductions in yield every year, the average loss in yield being slightly less than 50 percent in 1944, 1945 and 1946. The yield following heavy damage in 1943 was not decreased as much as in subsequent years. Two factors other than seasonal variations caused this result: (1) the severity of heavy damage was increased after 1943; (2) plants were not bruised in the 1943 test but were in 1944 through 1946.

TABLE 9. ANALYSIS OF VARIANCE OF YIELDS FOR SIMULATED HAIL TEST WITH LINCOLN AND RICHLAND SOYBEANS. 1944.

Source of variation	D. F.	Mean square
Whole plot—including checks on a sub-subplot basis:		
Rows	3	86.85
Columns	3	168.44
Degrees of damage	3	4,848.79
Error (a)	6	52.50
Subplot—including checks on a sub-subplot basis:		
Varieties	1	671.64
Varieties x degrees of damage	3	95.92
Error (b)	12	49.49
Sub-subplot—eliminating checks:		
Stages of growth	9	828.54
Stages of growth x degrees of damage	18	111.71
Stages of growth x varieties	9	47.17
Stages of growth x degrees of damage x varieties	18	14.69
Error (c)	162	10.12

Analyses of variance of yields (tables 6, 9 and 10) showed that the three degrees of damage caused considerable differences in yield each year. There was also a differential effect of injury at the various stages of growth, as indicated by the large differences among their mean yields each year. In practically all cases damage inflicted at stage 7 caused the greatest reductions in yield. In this period beans were beginning to develop in the pods. The effect of injury on yield at the earlier stages of growth was more variable than at later stages because of environmental in-

TABLE 10. ANALYSES OF VARIANCE OF YIELDS FOR SIMULATED HAIL TESTS WITH RICHLAND SOYBEANS.

Source of variation	D. F.	Mean squares			D. F.	Mean square 1944-46 combined
		1944	1945	1946		
Whole plot—including checks on a subplot basis:						
Rows	3	74.97	41.59	9.82	9	42.12
Columns	3	67.77	5.46	13.73	9	28.99
Degrees of damage	3	1,937.38	1,437.34	1,753.30	3	5,001.37
Years					2	890.41
Degrees of damage x years					6	63.32
Error (a)	6	46.10	7.32	10.98	18	21.47
Subplot—eliminating checks:						
Stages of growth	9	403.03	127.15	237.88	9	685.25
Stages of growth x degrees of damage	18	41.35	19.07	22.28	18	59.86
Stages of growth x years					18	41.40
Stages of growth x degrees of damage x years					36	11.42
Error (b)	81	7.60	2.09	4.50	243	4.73

fluences. Plant recovery was relatively good following light and medium damage at stages 1 and 3 in 1943 and at stage 2 in 1946. Medium damaged plots at stage 2 in 1944 recovered sufficiently well to outyield the check. On the other hand, significant decreases in yield were obtained with light and medium damage at stage 1 in 1944. Heavy damage at stage 1 reduced yields considerably more in 1945 and 1946 than in 1943 and 1944. These somewhat erratic results at the first three or four stages of growth show, therefore, that the environment influenced the amount of recovery.

Damages from approximately stages 4 to 7 reduced the yield progressively more for each successive stage. After stage 7 the losses in yield became smaller with each later

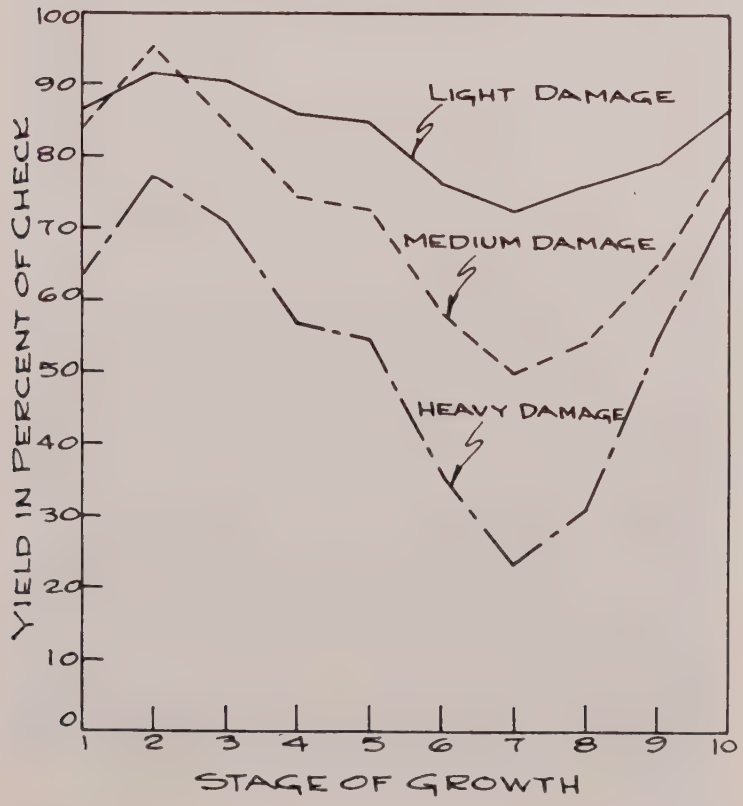

Fig. 14. Average yields in percent of check resulting from three degrees of simulated hail damage at 10 stages of plant development in Richland soybeans. 1944-46.

stage of plant development. Damage at the last few stages of growth was primarily mechanical in that losses were largely the result of pod removal. These results emphasize the importance of stage of plant development when injured as well as amount of injury in determining the effect of simulated hail damage to soybean yields.

Figure 14 shows that the greatest differences in yield reduction between all three degrees of damage in these tests were obtained at stages 6 through 8. Light and medium damage at stages 1 to 3 resulted in practically the same reductions in yield. It was this differential in yield between the stages of growth and the different degrees of damage that caused considerably large interactions in the 1944, 1945 and 1946 tests (see tables 9 and 10). This interaction was not high in the 1943 test (see table 6) because the damage inflicted was not as severe as in the last three years. The lack of an interaction between varieties and degrees of damage in the 1944 test indicated that the two varieties were affected in a similar manner by the three degrees of simulated hail injury. For this reason only Richland was utilized in the 1945 and 1946 tests.

The question might be asked: "Why do soybean plants damaged at certain stages of growth recover more than those damaged at other stages?" In all tests, recovery (measured by formation of new plant tissues) was greatest

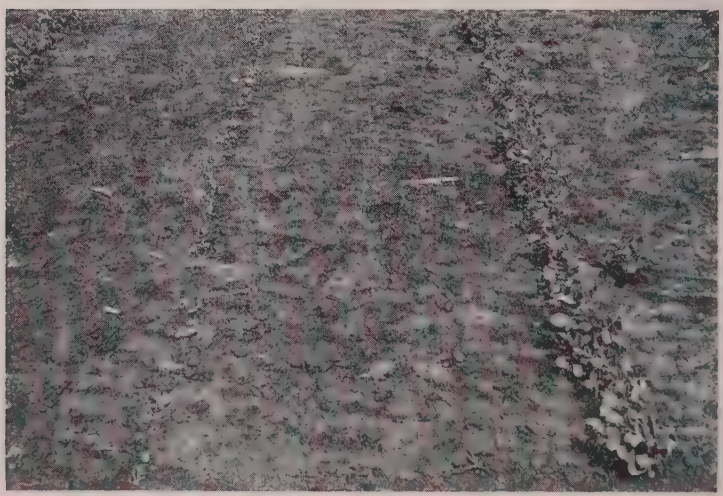

Fig. 15. At the left, a row in which all plants were cut off above the cotyledons at stage 1. Undamaged row at the right. Photo taken June 16, 1946.

Fig. 16. Plant showing the production of new stem branches which originated in the axils of the cotyledons 2 weeks after it was cut off above the cotyledons at stage 1. Photo taken July 3, 1946.

during the earlier stages of growth and practically nonexistent after stage 6. Plants damaged at stages 1 through 5 or 6 formed new leaves and branches to replace in part those lost. An illustration of this type of recovery is shown in figs. 15 to 17. Figure 15 shows a row after all plants were cut off above the cotyledons at stage 1. Most of these plants produced new stem branches in the axils

Fig. 17. At the right, a row showing recovery 1 month after all plants were cut off above the cotyledons at stage 1. Check row at the left. Photo taken July 17, 1946.

Fig. 18. From front to back, heavy damage at stages 4, 5, 3 and check taken at stage 5. Note the amount of recovery in 11 days on the row damaged at stage 3. Photo taken July 17, 1946.

of the cotyledons, in the manner shown in fig. 16, and a month later the row appeared as in fig. 17. However, some of the plants in these rows died, and as a result the stand was reduced. The plants which survived produced new branches and leaves and yielded an average of 63 percent of undamaged plants. Figure 18 shows three rows heavily damaged at the third, fourth and fifth stages of growth. One of the rows had already partially recovered by the regeneration of new leaves and branches when the photograph was taken. After full bloom (stage 5) the plants were not able to regenerate new leaves and stems, probably because the available food materials produced by the remaining leaves were used for pod and bean formation, or because terminal primordia had already developed into flowers and vegetative primordia no longer were functional. Consequently, damage at stages 6 through 9 resulted in greater reductions in yield than damage during the earlier stages of plant development.

OTHER AGRONOMIC CHARACTERS

Several other agronomic characters in addition to yield were markedly affected by the simulated hail injury inflicted in these tests. As shown by the maturity data in table 11, heavy damage had a profound effect on date of maturity. Heavy damage at the first six stages of growth delayed maturity an average of a week or more. Medium damage at the first five stages of growth delayed maturity about 3 days on the average. These effects were most noticeable at stages 1, 4 and 5. Light damage, on the other hand, appeared to have little effect on maturity. At the last two stages of growth there was a tendency for maturity to be hastened somewhat by all degrees of damage. Although seasonal variations influenced maturity, the general trends were similar each year.

All plots matured before frost in these investigations. Under actual farming conditions, however, most farmers grow full season varieties. Delays in maturity, therefore, would enhance the danger of frost injury, which might be the case when actual hailstorms occur during the early part of the growing season.

Plant height is important in harvesting soybeans. Short varieties such as Richland and Habaro bear many pods close to the ground. As a result, many such pods cannot be harvested with a combine. The effect of injury in decreasing plant height in these tests (table 11) emphasized the poten-

TABLE 11. EFFECT OF THREE DEGREES OF SIMULATED HAIL DAMAGE AT 10 STAGES OF GROWTH ON DATE OF MATURITY AND PLANT HEIGHT IN SOYBEANS.

Degree of damage	Stage of growth when damage inflicted	Maturities*		Heights			
		Richland Av. 1944-46	Lincoln 1944	Richland Av. 1944-46		Lincoln 1944	
				In.	% of check	In.	% of check
Check (no damage)		9-28	10-10	33		39	
Light damage	1	0	—1	31	94	36	92
	2	0	—1	32	97	38	97
	3	+1	0	30	91	35	90
	4	0	—1	30	91	36	92
	5	0	—1	30	91	37	95
	6	—2	—2	30	91	37	95
	7	—1	—1	32	97	38	97
	8	—2	—1	33	100	38	97
	9	—2	—2	32	97	38	97
	10	—2	—2	32	97	38	97
Medium damage	1	+3	+1	29	88	35	90
	2	+1	0	30	91	37	95
	3	+1	+1	28	85	32	82
	4	+5	+4	24	73	27	69
	5	+4	+2	25	76	29	74
	6	+1	—2	28	85	33	85
	7	—1	—5	30	91	37	95
	8	—1	—6	32	97	36	92
	9	—2	—6	32	97	36	92
	10	—3	—8	32	97	35	90
Heavy damage	1	+12	+3	25	76	33	85
	2	+6	+2	27	82	31	79
	3	+6	+4	24	73	27	69
	4	+10	+6	21	64	23	59
	5	+10	+6	19	58	24	62
	6	+7	+5	24	73	25	64
	7	+1	—3	30	91	32	82
	8	0	—6	31	94	33	85
	9	—2	—7	31	94	35	90
	10	—3	—8	31	94	36	92

*Maturity expressed as days later (+) or earlier (—) than average date of maturity for the check.

tial importance that this character might assume in the adjustment of severe hail losses. The greatest decreases in height occurred when damage was inflicted during the fourth and fifth stages of growth—during the blooming period. All degrees of damage, however, reduced the height at stages 1 through 6. At the last few stages of growth there was little effect on height. Increasing the severity of injury decreased plant height proportionately in every instance.

The data obtained on lodging were recorded but they are not reported here because they are not comparable to results in the field with actual hail. Hailstorms generally are accompanied with winds, and the combined effect of hail and wind causes considerable lodging. In these studies

damage decreased the lodging. In fact, the tendency was for the least lodging to occur with heavy damage. This probably was because the removal of plant parts lessened the weight on main stems in comparison to that found in undamaged plots.

Seed quality and seed size also were affected by the different degrees of damage. Seed quality is an important factor in determining the market price of soybeans. Table 12 shows that the quality of seed obtained from damaged plots was definitely poorer than seed from check plots. In general, seed quality became poorer as the severity of injury increased, with the poorest seed quality resulting from heavy damage at stages 8 and 9. Seed quality at these stages was sufficiently poor to justify a lower price than for undamaged beans.

TABLE 12. EFFECT OF THREE DEGREES OF SIMULATED HAIL DAMAGE AT 10 STAGES OF GROWTH ON SEED QUALITY AND SEED SIZE IN SOYBEANS.

Degree of damage	Stage of growth when damage inflicted	Seed quality indices*		Grams per 100 seeds			
				Richland Av. 1944-46		Lincoln 1944	
		Richland Av. 1944-46	Lincoln 1944	Gm.	% of check	Gm.	% of check
Check (no damage)		1.0	1.0	16.9		15.2	
Light damage	1	1.0	2.0	17.1	101	16.0	105
	2	1.0	1.8	17.1	101	15.8	104
	3	1.2	1.3	17.3	102	15.5	102
	4	1.0	1.3	16.9	100	15.5	102
	5	1.2	1.3	16.5	98	15.4	101
	6	1.1	1.3	16.7	99	15.1	99
	7	1.3	1.3	16.2	96	14.8	97
	8	1.0	1.3	15.9	94	14.7	97
	9	1.4	1.8	15.6	92	13.9	91
	10	1.3	1.8	16.2	96	14.4	95
Medium damage	1	1.2	1.3	17.1	101	16.1	106
	2	1.1	1.0	17.1	101	16.1	106
	3	1.3	1.8	16.7	99	15.9	105
	4	1.7	2.0	16.9	100	16.7	110
	5	1.6	1.8	16.6	98	16.0	105
	6	1.8	1.5	15.9	94	14.5	95
	7	1.8	1.8	15.5	92	14.3	94
	8	2.2	2.3	14.3	85	13.6	89
	9	2.0	2.5	14.4	85	12.8	84
	10	1.8	2.0	16.6	98	14.1	93
Heavy damage	1	1.5	1.8	18.1	107	16.3	107
	2	1.2	2.0	16.8	99	17.1	113
	3	1.7	1.8	17.1	101	17.2	113
	4	1.6	2.0	17.3	102	17.2	113
	5	1.5	2.0	16.8	99	16.6	109
	6	1.9	1.5	16.2	96	15.1	99
	7	2.2	2.0	14.6	86	12.6	83
	8	2.9	3.0	13.1	78	11.5	76
	9	2.6	3.0	13.5	80	11.5	76
	10	2.0	2.8	16.2	96	13.5	89

*Seed quality was scored on a scale ranging from 1 (very good) to 5 (very poor), considering seed development, seed coat defectiveness and color.

Data appearing in table 12 also show that seed size was appreciably decreased at stages 7 through 9 with all degrees of damage. Heavy damage at stage 8 caused an average reduction of 22 percent in seed size of Richland. In addition to affecting seed size, damage during the last three or four stages of growth produced many flat aborted seeds, only a few of which were found in seed from check plots. This effect on seed size was reflected in poorer quality seed during the later stages of plant development.

NON-WEEDED TEST

Weeds are one of the most serious menaces to profitable soybean production. Often hail during the first part of the growing season has greatly enhanced the growth of weeds in soybean fields by lessening the number and size of plants. In all previously discussed simulated hail tests the plots were hand-weeded to eliminate the influence of weed growth on results. In this test, conducted in 1946 only, the plots were not hand-weeded and damage was inflicted only at stages 1, 3, 5, 7 and 9. Data were collected on the effect of the different degrees of damage on agronomic characters, and observations were made on the effect of damage on weed growth.

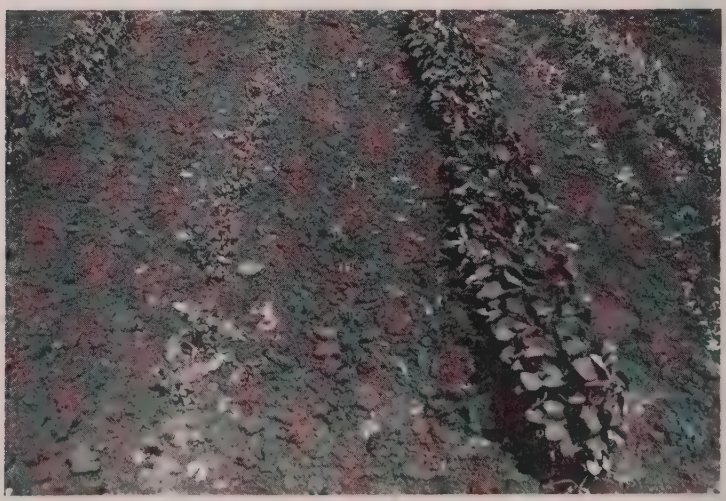

Fig. 19. On the left, a row showing the depleted stand and amount of recovery 19 days after all plants were cut off above the cotyledons at stage 1. Photo taken July 3, 1946.

Fig. 20. The center row shows weed growth which developed 7 weeks after all plants were cut off above the cotyledons at stage 1. Photo taken Aug. 5, 1946.

The only marked increase in weed growth followed heavy damage at stage 1, when all plants were cut off above the cotyledons. As previously stated, stand was reduced on plots subjected to such treatment, thereby leaving blank spaces for weeds to grow. This is illustrated in fig. 19, taken 19 days after heavy damage at stage 1. The prolific weed growth that resulted is shown in fig. 20. Damage at other stages did not cause appreciable increases in weed growth.

The agronomic data in table 13 include the measurements on maturity, lodging, seed quality, plant height and seed yield. The analysis of variance of the yields appears in table 14. Although this test was conducted in another field, the results were remarkably similar to those obtained in 1946 in the comparable hand-weeded test already discussed. The percentage reduction in yield resulting from heavy damage at stage 1, despite the added growth of weeds, was only slightly greater than that observed in the hand-weeded test. It is possible, however, that actual hail damage to farmers' fields during the earlier stages of growth may result in a greater growth of weeds and cause larger reductions in yield than observed in this test.

TABLE 13. EFFECT OF THREE DEGREES OF SIMULATED HAIL DAMAGE AT FIVE STAGES OF GROWTH ON MATURITY, LODGING, SEED QUALITY, PLANT HEIGHT AND SEED YIELD OF SOYBEANS ON PLOTS NOT HAND-WEEDED. 1946.

Degree of damage	Stage of growth when damage inflicted	Maturity*	Lodging score	Seed quality index	Height		Yield	
					Inches	Percent of check	Bu/A	Percent of check
Check (no damage)		9-20	1.4	1.0	31		29.7	
Light damage	1	+ 1	1.3	1.0	29	94	27.7	93
	3	+ 1	1.5	1.0	28	90	27.4	92
	5	+ 1	1.0	1.0	28	90	25.2	85
	7	0	1.0	1.0	30	97	24.2	81
	9	— 1	1.0	1.0	31	100	24.9	84
Mean							25.9	87
Medium damage	1	+ 5	1.5	1.0	29	94	27.3	92
	3	+ 4	2.0	1.0	25	81	25.7	87
	5	+ 9	1.3	1.0	18	58	19.7	66
	7	+ 2	1.5	1.3	26	84	15.9	54
	9	+ 1	1.0	1.8	30	97	19.3	65
Mean							21.6	73
Heavy damage	1	+16	1.0	1.3	25	81	15.8	53
	3	+ 8	1.5	1.0	22	71	23.6	79
	5	+15	1.0	1.0	15	48	15.8	53
	7	+ 5	2.0	1.3	27	87	8.2	28
	9	+ 1	1.3	2.3	30	97	16.0	54
Mean							15.9	54

*Maturity expressed as days later (+) or earlier (—) than average date of maturity for check.

TABLE 14. ANALYSIS OF VARIANCE OF YIELDS IN SIMULATED HAIL TEST ON PLOTS NOT HAND-WEEDED. 1946.

Source of variation	D. F.	Mean square
Whole plot—including checks on a subplot basis:		
Rows	3	38.80
Columns	3	41.80
Degrees of damage	3	702.28
Error (a)	6	7.45
Subplot—eliminating checks:		
Stages of growth	4	158.48
Stages of growth x degrees of damage	8	30.51
Error (b)	36	2.78

CHEMICAL COMPOSITION OF THE SEED

Several chemical characteristics of soybean seed are considered of industrial importance. These include protein and oil percentage and iodine number of the oil. Consequently, it seemed desirable to determine whether or not the injuries inflicted affected these characteristics, as any marked changes would concern the soybean processors.

TABLE 15. EFFECT OF THREE DEGREES OF SIMULATED HAIL DAMAGE AT 10 STAGES OF GROWTH ON PROTEIN AND OIL PERCENTAGE OF THE SEED AND ON IODINE NUMBER OF THE OIL.

Degree of damage	Stage of growth when damage inflicted	Protein percentage		Oil percentage		Iodine no. of oil	
		Richland average 1944-46	Lincoln 1944	Richland average 1944-46	Lincoln 1944	Richland average 1944-46	Lincoln 1944
Check (no damage)		41.9	41.4	20.0	20.2	127.5	137.4
Light damage	1	41.6	41.9	20.0	20.3	127.9	136.8
	2	41.9	41.6	19.8	20.3	128.2	136.6
	3	41.9	42.4	19.8	20.2	127.8	137.3
	4	41.7	42.1	19.9	20.4	127.7	137.4
	5	41.8	42.1	19.9	20.5	127.8	137.2
	6	41.7	41.2	20.1	20.6	128.7	137.4
	7	41.3	41.3	19.9	20.6	129.8	137.7
	8	40.8	41.6	19.9	20.3	130.0	138.3
	9	41.1	41.1	19.7	20.3	29.0	137.7
	10	41.3	41.6	20.2	20.3	127.6	138.0
Medium damage	1	41.0	42.2	19.8	20.1	128.7	136.5
	2	41.0	41.7	19.7	20.5	128.1	137.0
	3	41.4	42.0	19.7	20.3	128.1	137.7
	4	41.1	43.2	19.6	19.6	129.2	136.9
	5	41.5	42.1	19.7	20.0	129.0	137.2
	6	41.2	41.1	19.9	20.4	130.9	138.0
	7	41.2	40.5	19.7	20.4	132.0	138.9
	8	40.6	41.2	19.2	19.6	133.3	139.4
	9	41.3	41.6	19.1	19.4	130.1	138.7
	10	41.3	41.2	19.9	20.3	128.0	138.6
Heavy damage	1	42.2	42.0	19.2	19.7	130.8	137.4
	2	41.6	43.4	19.4	19.4	128.8	137.2
	3	42.0	43.0	19.1	19.4	129.2	137.2
	4	42.0	43.1	19.3	18.9	130.5	137.5
	5	42.2	43.5	19.4	19.4	130.4	137.4
	6	41.8	41.9	19.1	19.1	132.2	138.0
	7	41.9	42.1	18.9	18.9	134.9	141.4
	8	42.4	42.7	17.6	17.2	134.8	142.0
	9	41.8	42.1	18.6	18.4	130.1	139.4
	10	41.6	42.2	19.7	19.9	127.8	139.1

Table 15 shows that protein percentage was not appreciably affected by any degree of damage at any stage of growth. Variations in protein percentages were of a random nature expected due to seasonal fluctuations in the environment and to sampling. Oil percentage of the seed, however, appeared to be affected by heavy damage and to some extent by medium damage. Seed from heavily damaged plots was consistently lower in average oil percentage than seed from undamaged plots. The greatest decrease in oil content occurred at stages 8 and 9 with both the medium and heavy degrees of injury. Light damage caused little perceptible effect on oil percentage at any stage of growth. These results indicated that severe hail injury during the period of bean formation may cause not only large reductions in yield but also substantial decreases in oil content of the seed.

Iodine number of the oil was increased by the three de-

grees of damage at certain stages (table 15). There was an increase in iodine number of the oil for all degrees of damage at stages 6, 7 and 8 with Richland. This tendency was apparent for Lincoln only with medium and heavy damage during the same stages. Damage before full bloom stage or after the pods were well filled did not have such a marked effect on iodine number of the oil.

TABLE 16. EFFECT OF REDUCING STAND AT TWO HEIGHTS AND FIVE STAGES OF GROWTH ON YIELD OF SEED IN SOYBEANS.

Percent stand reduction	Stage of growth when stand removed	1945		1946		Average 1945-46	
		Bu/A	Percent of check	Bu/A	Percent of check	Bu/A	Percent of check
		Plants cut off at ground level					
Check (no stand reduction)		32.3		35.8		34.0	
25% reduction	1	32.1	99	37.0	103	34.6	102
	3	31.0	98	36.4	102	33.2	98
	5	28.5	88	35.9	100	32.2	95
	7	26.4	82	31.6	88	29.0	85
	9	26.0	80	31.3	87	28.7	84
Mean		28.6	89	34.4	96	31.5	93
50% reduction	1	31.2	97	35.1	98	33.2	98
	3	29.4	91	33.4	93	31.4	92
	5	26.0	80	29.4	82	27.7	81
	7	19.0	59	24.2	68	21.6	64
	9	18.5	57	20.1	56	19.3	57
Mean		24.8	77	28.4	79	26.6	78
75% reduction	1	25.3	78	34.8	97	30.1	89
	3	22.5	70	28.1	78	25.3	74
	5	18.4	57	23.7	66	21.0	62
	7	10.7	33	15.6	44	13.1	39
	9	8.5	26	9.8	27	9.1	27
Mean		17.1	53	22.4	63	19.7	58
		Plants cut off at one-half their height					
Check (no stand reduction)		32.6		35.5		34.0	
25% reduction	1	31.7	97	36.7	103	34.2	101
	3	31.5	97	33.7	95	32.6	96
	5	29.6	91	36.6	103	33.1	97
	7	28.2	87	32.8	92	30.5	90
	9	28.4	87	31.9	87	29.6	87
Mean		29.9	92	34.1	96	32.0	94
50% reduction	1	31.6	97	34.2	96	32.9	97
	3	28.3	87	33.8	95	31.1	91
	5	28.7	88	32.6	92	30.6	90
	7	23.0	71	29.6	83	26.3	77
	9	24.7	76	24.1	68	24.4	72
Mean		27.2	83	30.9	87	29.0	85
75% reduction	1	29.0	89	36.5	103	32.8	96
	3	24.8	76	32.9	93	28.9	85
	5	23.0	71	32.0	90	27.5	81
	7	18.5	57	26.5	75	22.5	66
	9	18.1	56	21.8	61	20.0	59
Mean		22.7	70	29.9	84	26.3	77

STAND REDUCTION TESTS

(1945 and 1946)

It is relatively common for hailstorms in soybean fields to break over plants or cut out varying portions of the stand. When these investigations were initiated little was known regarding the effect of stand losses at various stages of plant development on yield and other agronomic characters. These tests were conducted, therefore, to obtain experimental data on this subject.

SEED YIELD

In both 1945 and 1946 plot stands were reduced by 25, 50 or 75 percent at each of two heights: one at ground level and the other at one-half the height of the plants. Both heights were treated at five stages of growth. The yields from these treatments appear in table 16.

It was apparent that the effect of reduced stand on seed

TABLE 17. ANALYSES OF VARIANCE OF YIELDS FOR STAND REDUCTION TESTS.

Source of variation	1945		1946		1945 & 1946 combined	
	D. F.	Mean square	D. F.	Mean square	D. F.	Mean square
Whole plot—including checks on a sub-subplot basis:						
Rows	3	7.73	3	17.09	6	12.41
Columns	3	4.41	3	11.71	6	8.06
Percentages of stand reduction	3	1149.21	3	753.57	3	1862.54
Years					1	1649.38
Percentages of stand reduction x years					3	40.24
Error (a)	6	12.69	6	4.94	12	8.82
Subplot—eliminating checks on a sub-subplot basis:						
Heights	1	288.61	1	312.98	1	601.35
Heights x percentages of stand reduction	2	51.14	2	158.86	2	194.83
Heights x years					1	.24
Heights x percentages of stand reduction x years					2	15.17
Error (b)	9	2.68	9	6.98	18	4.83
Sub-subplot—eliminating checks:						
Stages of growth	4	416.91	4	630.39	4	1019.28
Stages x percentages of stand reduction	8	31.72	8	63.40	8	87.48
Stages x heights	4	29.13	4	39.81	4	64.93
Stages x years					4	28.01
Stages x percentages of stand reduction x heights	8	4.14	8	7.62	8	7.87
Stages x percentages of stand reduction x years					8	7.64
Stages x heights x years					4	4.02
Stages x percentages of stand reduction x heights x years					8	3.89
Error (c)	72	2.55	72	3.84	144	3.19

yields became progressively greater as stand was removed later in the season. The removal of 25 or 50 percent of the stand at stage 1 did not cause an appreciable decrease in yield either year. Removing 75 percent of the stand at the same stage, however, caused a marked decrease in yield in 1945 but not in 1946. This was due in part to the better conditions for plant recovery during the early part of the growing season in 1946 than in 1945. The greatest decreases in yield, with one exception, occurred when stands were reduced at stage 9, the "green bean" stage. The data did not show noticeable differences in yield between stands

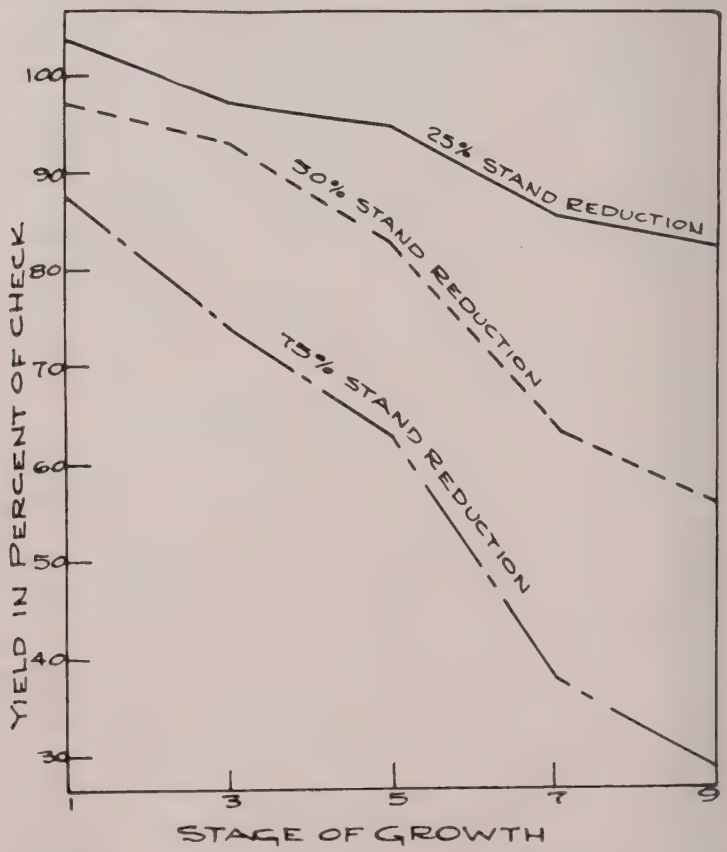

Fig. 21. Average yields in percent of check resulting from the reduction of stand at ground level at five stages of plant development. 1945-46.

reduced at ground level and at one-half height at stages 1 and 3 when 25 or 50 percent of the plants were removed. At the later stages, however, stand reduction at ground level resulted in greater decreases in yield than at one-half height. This was true for all stages of growth when 75 percent of the stand was removed.

Analyses of variance of the yields, shown in table 17, indicated that each of the main effects—namely, percentages of stand reduction, heights of stand reduction and stages of growth—resulted in large mean differences in yield among themselves. The magnitude of the interaction between percentages of stand reduction and years indicated that the yields were probably not affected to the same extent in 1945 that they were in 1946 by the different percentages of stand reduction. It has already been mentioned that plant recovery was better in 1946 than in 1945, which explains in part this interaction and also the rather large mean square for the interaction of stages × percentages of stand reduction × years.

During the early stages of growth the differences in yields between the percentages of stand removal were relatively small. At the later stages, however, these differences were

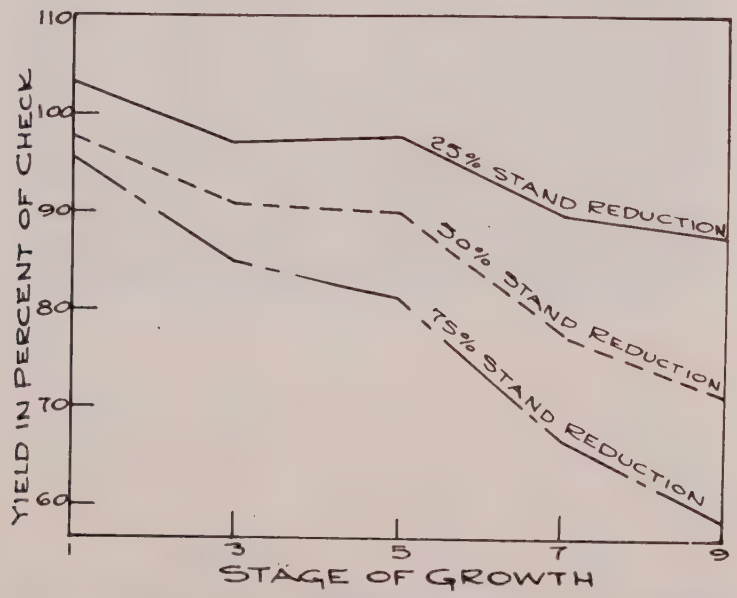

Fig. 22. Average yields in percent of check resulting from the reduction of stand at one-half the height of the plants at five stages of plant development. 1945-46.

Fig. 23. Plant cut off at one-half its height at stage 3 showing recovery by the production of new branches from the axils of the leaves. Photo taken July 20, 1946.

considerably greater. This was substantiated by the relatively large mean squares for the interaction between stages of growth $\times$ percentages of stand reduction in the analyses of variance (table 17). The yields in percent of check are shown in figs. 21 and 22.

The ability of the remaining plants to compensate in part for the removal of different percentages of the original plants was dependent on the production of additional stem branches. This ability was greatest at the first stage of

growth. From stages 1 through 5 the amount of additional branching was progressively less until at stages 7 and 9 it was entirely lacking. Rows in which different percentages of the plants were cut off at one-half their height compensated for this loss to some extent by the production of additional branches on undamaged as well as damaged plants. Figure 23 shows the production of new branches in the axils of remaining leaves on a plant cut off at one-half its height at stage 3. The amount of new or additional

TABLE 18. EFFECT OF REMOVING STAND AT TWO HEIGHTS AND FIVE STAGES OF GROWTH ON DATE OF MATURITY, PLANT HEIGHT AND LODGING IN SOYBEANS.

Percent stand reduction	Stage of growth when stand removed	Average 1945-46			
		Maturity*	Height		Lodging score
			Inches	Percent of check	
		Plants cut off at ground level			
Check (no stand reduction)		9-28	32		2.4
25% reduction	1	0	32	100	1.9
	3	—1	31	97	1.6
	5	—1	31	97	1.5
	7	0	31	97	2.5
	9	—1	32	100	2.3
50% reduction	1	0	31	97	1.6
	3	—1	30	94	1.3
	5	—1	29	91	1.0
	7	—1	30	94	2.4
	9	—3	31	97	2.3
75% reduction	1	0	30	94	1.5
	3	0	27	84	1.0
	5	—1	27	84	1.0
	7	—1	30	94	2.3
	9	—3	32	100	2.1
		Plants cut off at one-half their height			
25% reduction	1	—1	32	100	1.6
	3	—1	33	103	1.6
	5	—1	32	100	1.6
	7	0	32	100	2.4
	9	—1	32	100	2.4
50% reduction	1	0	32	100	1.6
	3	0	32	100	1.8
	5	0	31	97	1.3
	7	—1	32	100	2.4
	9	—1	32	100	2.5
75% reduction	1	+1	31	97	2.3
	3	0	28	88	1.9
	5	+2	28	88	1.1
	7	0	31	97	1.6
	9	—2	32	100	2.4

*Maturity expressed as days later (+) or earlier (—) than average date of maturity for check.

stem branching increased as the percentages of stand removed were increased at either height. This increase, however, was not directly proportional to the additional amounts of stand removed. As a result, stands were most nearly compensatory with 25, less with 50 and the least with 75 percent stand removal. All plants cut off at the ground level died.

OTHER AGRONOMIC CHARACTERS

The effect of removing stand on agronomic characters other than yield was relatively insignificant. The data obtained on date of maturity, plant height and lodging are found in table 18. Plant height was decreased noticeably only when 75 percent of the stand was removed at stages 3 and 5. A slight decrease in height resulted from 50 percent stand removal at ground level during the same period. There was a slight hastening of maturity with 50 and 75 percent stand reduction at stage 9, as this permitted pods to dry faster on the remaining plants.

As indicated by the lodging scores in table 18, the least lodging occurred during the early stages of growth with all percentages of stand reduction. This was due to lessened competition and formation of thicker stems on remaining plants. Lodging at stages 7 and 9 approximated that of the check, irrespective of the percentage of stand removed. These data indicated, therefore, that stand reduction alone did not have enough influence on agronomic characters other than yield to merit much consideration.

DEFOLIATION TESTS

(1945 and 1946)

SEED YIELD

All hailstorms destroy some of the leaves. In the defoliation tests, 10, 25, 50, 75 and 100 percent of only the leaves were removed from plots of Richland soybeans at five stages of plant development to determine the effect on yield and other characters. Yields following these treatments are shown in table 19. Apparently the effect of defoliation on yield was greatest at stage 7, the beginning of bean formation in the pods. Little or no reduction in yield resulted when 10, 25, 50 and even 75 percent of the leaves were removed at stages 1 and 3. Removal of all leaves at the same stages, however, caused a marked decrease in yield. In no case was the decrease in yield proportional to the percentage of leaves removed.

TABLE 19. EFFECT OF FIVE PERCENTAGES OF DEFOLIATION AT FIVE STAGES OF GROWTH ON YIELD OF SEED IN SOYBEANS.

Percent defoliation	Stage of growth when defoliated	1945		1946		Average 1945-46	
		Yield Bu./A.	Percent of check	Yield Bu./A.	Percent of check	Yield Bu./A.	Percent of check
Check (no defoliation)		36.3		36.7		36.5	
10% defoliation	1	35.3	97	37.2	101	36.2	99
	3	38.3	106	34.6	94	36.5	100
	5	35.0	96	36.4	99	35.7	98
	7	31.9	88	35.0	95	33.4	92
	9	32.7	90	35.3	96	34.0	93
Mean		34.7	96	35.7	97	35.2	96
25% defoliation	1	34.2	94	35.7	97	35.0	96
	3	36.0	99	36.0	98	36.0	99
	5	34.3	94	35.5	97	34.9	96
	7	30.9	85	32.6	89	31.7	87
	9	33.9	93	35.1	96	34.5	95
Mean		33.9	93	35.0	95	34.4	94
50% defoliation	1	35.1	97	35.8	98	35.4	97
	3	35.2	97	36.1	98	35.7	98
	5	33.1	91	33.1	90	33.1	91
	7	27.2	75	32.4	88	29.8	82
	9	33.4	92	34.2	93	33.8	93
Mean		32.8	90	34.3	93	33.5	92
75% defoliation	1	35.0	96	34.5	94	34.7	95
	3	34.4	95	32.8	89	33.6	92
	5	31.1	86	30.7	84	30.9	85
	7	23.9	66	22.9	62	23.4	64
	9	31.5	87	31.2	85	31.4	86
Mean		31.2	86	30.4	83	30.8	84
100% defoliation	1	30.8	85	29.1	79	29.9	82
	3	27.2	75	26.9	73	27.0	74
	5	22.7	63	23.3	63	23.0	63
	7	5.5	15	7.1	19	6.3	17
	9	26.0	72	23.1	63	24.5	67
Mean		22.4	62	21.9	60	22.2	61

TABLE 20. ANALYSES OF VARIANCE OF YIELDS FOR DEFOLIATION TESTS.

Source of variation	1945		1946		Combined 1945-46	
	D. F.	Mean square	D. F.	Mean square	D. F.	Mean square
Whole plot—including checks on a subplot basis:						
Replications	3	81.68	3	34.88	6	58.28
Years					1	13.54
Percentages of defoliation	5	488.57	5	614.62	5	1094.70
Percentages of defoliation x years					5	8.49
Error (a)	15	10.77	15	2.08	30	6.42
Subplot—eliminating checks:						
Stages of growth	4	355.10	4	210.44	4	553.36
Stages of growth x years					4	12.17
Percentages of defoliation x stages of growth	16	49.15	16	47.32	16	91.65
Percentages of defoliation x stages of growth x years					16	4.82
Error (b)	60	3.64	60	4.63	120	4.14

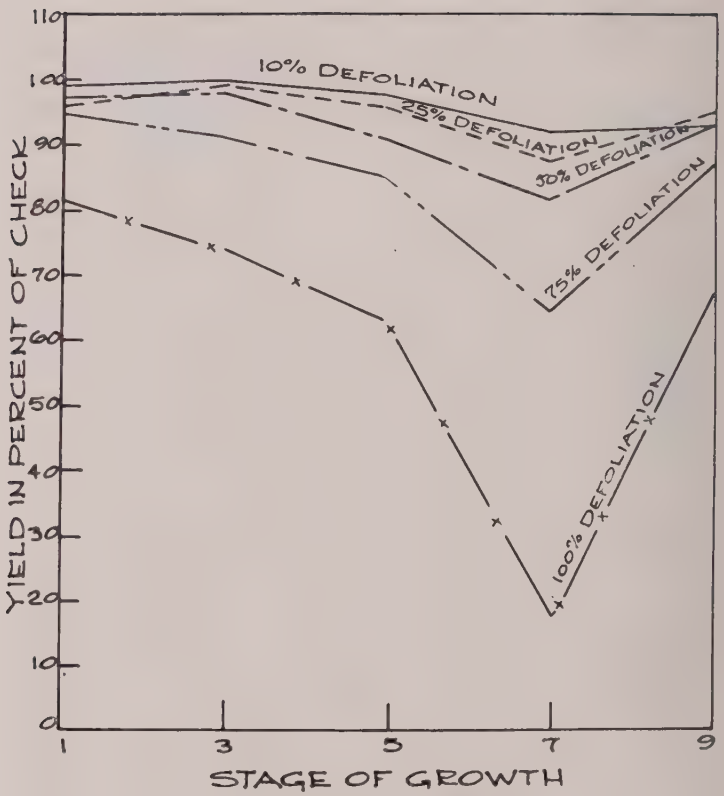

Fig. 24. Average yields in percent of check resulting from five percentages of defoliation at five stages of plant development. 1945-46.

Analyses of variance of the yields (table 20) showed that mean differences between percentages of defoliation and between stages of growth were large. The small mean square between percentages of defoliation × years indicated that the effect of defoliation on yield was very similar during the two years. On the other hand, the interaction between percentages of defoliation and stages of growth was of considerable magnitude. The interaction was accounted for by the fact that the average effects of the five percentages of defoliation on yield were not the same at the different stages of growth. As shown in fig. 24 the spread in yield resulting from the five percentages of defoliation was considerably less at stages 1, 3, 5 and 9 than at stage 7. Also

Fig. 25. Plant showing new leaf development 11 days after 100 percent of its leaves were removed at stage 3. Photo taken July 17, 1946.

the trends in yield reduction were similar to those obtained in the simulated hail tests; they were smaller, however, primarily because leaf removal was the only injury to the plants.

Plants which had varying percentages of leaves removed at stages 1, 3 and 5 compensated for some of this loss by producing new leaves from terminal and axillary buds. This

phenomenon is illustrated in fig. 25, which shows a plant that had 100 percent of its leaves removed at stage 3. The formation of new leaves was greatest at stage 1, less at stages 3 and 5, only slightly evident at stage 7 and nonexistent at stage 9. The primary reason for the greatest decreases in yield at stage 7 was the lack of food material necessary for bean formation in the pods. As a result, many pods aborted. Figure 26 shows the resulting abortion on a plant 100 percent defoliated at stage 7, as compared to a normally developed plant. Yields at stage 9 were not decreased as much by defoliation as at stage 7 because most of the beans in the pods were almost fully developed by that time.

OTHER AGRONOMIC CHARACTERS

Data showing the effect of defoliation on maturity, height, lodging and seed size appear in table 21. Total defoliation at stages 1, 3 and 5 resulted in a 4- to 5-day average delay in maturity. Maturity was hastened several days by 75 percent defoliation at stages 7 and 9 and 100 percent defoliation at stage 9. Lesser amounts of defoliation had little effect on maturity. Lodging was noticeably decreased with the larger percentages of defoliation, especially at stages 5 and 7. Similarly, plant height was appreciably decreased only by 100 percent defoliation at the first three stages of growth.

Fig. 26. Stem at left shows normally developed pods and beans. Stem at right shows aborted pods resulting from 100 percent defoliation at stage 7. Photo taken Sept. 18, 1946.

Figure 27 shows a row from which all the leaves were removed at stage 1, when the plants were 4 to 5 inches tall. This photograph was taken 2½ weeks later and shows the amount of recovery in comparison to a check row. It serves to illustrate why the complete removal of leaves at the early stages caused a delay in maturity and reduction

TABLE 21. EFFECT OF FIVE PERCENTAGES OF DEFOLIATION AT FIVE STAGES OF GROWTH ON DATE OF MATURITY, PLANT HEIGHT, LODGING AND SEED SIZE IN SOYBEANS.

Percent defoliation	Stage of growth when defoliated	Averages 1945-46					
		Maturity*	Lodging score	Height		Seed size	
				Inches	Percent of check	Gms. per 100 seeds	Percent of check
Check (no defoliation)		9-27	2.5	32		17.1	
10% defoliation	1	+1	2.4	32	100	17.6	103
	3	+1	2.4	31	97	18.1	106
	5	+1	2.3	32	100	18.1	106
	7	−1	2.1	32	100	17.8	104
	9	0	2.4	32	100	17.5	102
25% defoliation	1	+1	2.1	32	100	17.8	104
	3	0	2.0	31	97	17.7	104
	5	0	2.3	32	100	17.7	104
	7	−1	1.9	32	100	17.2	101
	9	0	2.3	32	100	16.9	99
50% defoliation	1	0	2.3	32	100	17.7	104
	3	0	2.4	31	97	17.6	103
	5	0	1.9	31	97	17.4	102
	7	−2	1.9	32	100	16.5	96
	9	−1	1.9	33	103	16.3	95
75% defoliation	1	+1	2.1	31	97	17.7	104
	3	−1	2.1	31	97	17.2	101
	5	0	1.3	30	94	17.1	100
	7	−5	1.5	32	100	15.4	90
	9	−2	2.1	32	100	15.3	89
100% defoliation	1	+5	1.6	29	91	17.9	105
	3	+5	1.9	27	84	17.3	101
	5	+4	1.1	26	81	16.1	94
	7	0	1.1	30	94	12.0	70
	9	−4	2.1	33	103	12.9	75

*Maturity expressed as days later (+) or earlier (−) than average date of maturity for check.

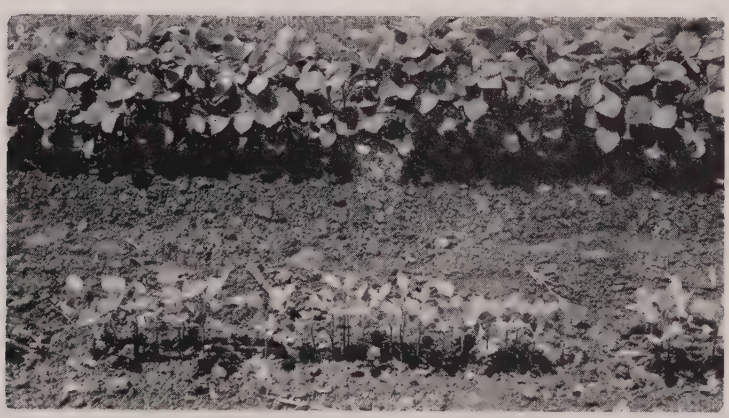

Fig. 27. In foreground, a row showing the amount of recovery in 2½ weeks following the removal of 100 percent of its leaves at stage 1. Compare with second row which was not defoliated. Photo taken July 6, 1946.

Fig. 28. From left to right, rows showing the effect on date of maturity and plant height of 100 percent leaf removal at stages 1, 3, 5, 7 and 9. Photo taken Sept. 18, 1946.

in height. Another illustration of the effect of 100 percent defoliation on maturity and height at the five stages of plant development is shown in fig. 28. This photograph was taken in mid-September when the plots were approaching maturity. The delay in maturity at stages 1, 3 and 5 and the decrease in plant height at stage 5 are especially noticeable.

Seed quality was slightly poorer following 100 percent defoliation at stages 7 and 9 but otherwise similar to the non-defoliated check. Consequently, data for this character are omitted. Results for seed size (table 21), on the other hand, showed that it was affected more by defoliation than any other character except yield. Seed size was decreased 25 to 30 percent at stages 7 and 9 following 100 percent leaf removal. Removing 75 percent of the leaves at the same stages decreased seed size about 10 percent. In most cases slight increases in seed size resulted from defoliation during the early stages of plant development. When these effects on seed size were compared with the results obtained in the simulated hail tests (table 12) it appeared probable that the major factor contributing to decreases in seed size was loss of leaves.

CHEMICAL COMPOSITION OF THE SEED

Seed from the defoliation tests was analyzed for the same chemical characteristics as seed from the simulated hail tests. In 1945 seed from each replication of the five per-

TABLE 22. EFFECT OF FIVE PERCENTAGES OF DEFOLIATION AT FIVE STAGES OF GROWTH ON THE CHEMICAL COMPOSITION OF SOYBEAN SEED.

Percent defoliation	Stage of growth when defoliated	Protein percentage			Oil percentage			Iodine no. of oil		
		1945	1946	Average 1945-46	1945	1946	Average 1945-46	1945	1946	Average 1945-46
Check (no defoliation)		41.8	41.1	41.5	20.1	19.7	19.9	126.9	127.6	127.3
10% defoliation	1	41.8	41.7	41.8	19.9	20.2	20.1	127.3	128.0	127.7
	3	42.0	41.8	41.9	19.8	19.6	19.7	127.9	127.0	127.5
	5	42.2	41.7	42.0	19.9	19.9	19.9	126.9	126.9	126.9
	7	41.7	40.7	41.2	19.8	19.9	19.9	128.1	127.4	127.8
	9	41.9	41.0	41.5	20.0	20.1	20.1	27.2	127.8	127.5
Mean		41.9	41.4	41.7	19.9	19.9	19.9	127.5	127.4	127.5
25% defoliation	1	42.1	41.3	41.7	20.0	19.8	19.9	127.4	127.3	127.4
	3	41.9	41.2	41.6	19.9	19.6	19.8	126.5	127.5	127.0
	5	41.9	42.2	42.1	20.3	19.7	20.0	126.8	127.1	127.0
	7	41.7	41.0	41.4	20.3	19.9	20.1	128.0	127.6	127.8
	9	41.7	40.4	41.1	20.1	19.9	20.0	127.1	128.8	128.0
Mean		41.7	41.2	41.6	20.1	19.8	20.0	127.2	127.7	127.4
50% defoliation	1	41.9	41.5	41.7	19.7	19.9	19.8	127.5	127.6	127.6
	3	40.9	41.5	41.2	20.0	19.9	20.0	127.4	127.7	127.6
	5	41.6	40.9	41.3	20.1	20.6	20.4	127.2	127.7	127.5
	7	41.2	41.0	41.1	20.6	20.0	20.3	129.9	128.3	129.1
	9	40.8	41.0	40.9	20.4	20.0	20.2	127.9	129.9	128.9
Mean		41.3	41.2	41.2	20.1	20.1	20.1	128.0	128.2	128.1
75% defoliation	1	41.5	41.3	41.4	20.1	20.0	20.1	127.1	127.7	127.4
	3	41.8	40.8	41.3	20.3	20.1	20.2	126.6	127.3	127.0
	5	41.6	41.3	41.5	20.2	19.9	20.1	126.2	127.2	126.7
	7	40.1	40.9	40.5	20.8	20.1	20.5	130.4	130.6	130.5
	9	41.2	40.9	41.1	20.1	19.6	19.9	127.3	132.3	129.8
Mean		41.2	41.0	41.2	20.3	19.9	20.2	127.5	129.0	128.3
100% defoliation	1	41.4	41.3	41.4	19.8	20.2	20.0	128.4	128.6	128.5
	3	41.3	41.9	41.6	19.8	20.0	19.9	128.9	128.9	128.9
	5	40.9	41.7	41.3	20.2	20.0	20.1	128.8	130.8	129.8
	7	42.4	41.0	41.7	17.8	19.2	18.5	138.1	137.7	137.9
	9	41.6	43.0	42.3	19.0	17.2	18.1	126.0	135.7	130.9
Mean		41.5	41.8	41.7	19.3	19.3	19.3	130.0	132.3	131.2

centages of defoliation at each stage of growth was analyzed separately to obtain a measure of experimental error. A composite sample of seed from the four replications was used for chemical analyses in 1946. The chemical composition data appear in table 22. They reveal that protein percentage of the seed was not appreciably affected by leaf removal except possibly by 100 percent defoliation at stage 9 in 1946. Oil percentage was noticeably decreased only by 100 percent defoliation at stages 7 and 9. Iodine number of the oil was definitely increased by 50, 75 and 100 percent defoliation at stage 7 in both years and also at stage 9 in 1946. These results indicate that leaf loss was the primary factor contributing to the alterations in chemical composition of the seed noted in the simulated hail tests.

Analyses of variance of the 1945 chemical data, eliminating checks, are recorded in table 23. They further confirm the fact that variations in protein percentage of the seed in 1945, as a consequence of the defoliation treatments, were primarily of a random nature. The analyses indicated that percentage of defoliation means for both oil content and iodine number were significantly different, as were stage of growth means for the same characters. As noted in table 22, the greatest proportion of the variances of the means of oil content and iodine number was contributed by the larger percentages of defoliation at stages 7 and 9. It is apparent from these results, therefore, that loss of large amounts of leaf area during the period of pod and bean formation may have a marked effect on chemical composition of the seed.

TABLE 23. ANALYSES OF VARIANCE OF PROTEIN PERCENTAGE, OIL PERCENTAGE AND IODINE NUMBER OF THE OIL FOR SEED OBTAINED FROM THE DEFOLIATION TEST IN 1945. (CHECKS NOT INCLUDED)

Source of variation	D. F.	Mean squares		
		Protein percentage	Oil percentage	Iodine number of the oil
Whole plot—on subplot basis				
Replications	3	5.79	.51	.98
Percentages of defoliation	4	1.86	2.91	26.50
Error (a)	12	1.11	.12	1.01
Subplot				
Stages of growth	4	.33	.21	51.45
Percentages of defoliation x stages of growth	16	.97	1.08	13.24
Error (b)	60	.31	.06	.55

SIMULATED SHATTER TEST
(1946)

Although seed shattering in soybeans, as a consequence of hail, is uncommon in Iowa, it occurs frequently enough to merit consideration. In 1946, a test was conducted to determine the relationship between estimated and actual shatter losses in bushels per acre for the Richland variety. The average seed size in grams per 100 seeds for Richland from 1943 and 1945 at Ames was used to determine the approximate number of beans required to give nine levels of simulated shatter loss in bushels per acre. At maturity these estimated amounts of seed were removed from replicated 8-foot rows spaced 42 inches apart. The seed was then threshed, weighed and calculated in bushels per acre. The data in table 24 reveal that the estimated and actual losses were in close agreement, except possibly for the 24-bushel level. Since the actual seed weight in 1946 was 1.2 grams per 100 seeds larger than the weight used to estimate the nine levels of shatter loss, the actual amounts of seed removed should have been greater than observed. The good agreement, therefore, probably was due to removal of beans in the pods and threshing before weighing. The beans lost during the threshing operations tended to decrease the weight of the beans removed.

This test was of a preliminary nature and was intended as a preview of the effect of seed size on the estimation of shatter losses. Since soybean varieties differ markedly in seed size, this factor should be considered in the calculation of shatter losses from hail.

TABLE 24. NUMBER OF BEANS REMOVED ON THE BASIS OF PREVIOUS YEARS' SEED SIZE DATA TO OBTAIN A GIVEN SHATTER LOSS AND THE ACTUAL SHATTER LOSS IN BUSHELS PER ACRE THAT RESULTED. 1946.

Desired simulated shatter loss Bu./A.	Number beans removed		Actual simulated shatter loss Bu./A.
	Per sq. yd.	Per plot	
0	0	0	0
3	103	320	3.2
6	206	640	6.0
9	309	960	9.0
12	411	1280	11.6
15	514	1600	15.4
18	617	1920	17.8
21	720	2240	20.8
24	823	2561	26.1
27	926	2881	26.9

Average seed size of Richland at Ames from 1943 to 1945 in grams per 100 seeds = 16.4
Average seed size of Richland at Ames in 1946 in grams per 100 seeds = 17.6

DISCUSSION

At the time these investigations were initiated several divergent viewpoints existed regarding the relative importance of different factors in estimating hail losses to soybeans. Included among these factors were: leaf damage, stem damage, pod removal, loss of flowers, weather conditions, weed growth and varietal differences. Some of the prevailing differences in opinion were personal. Most of them, however, were due primarily to a lack of experience and experimental evidence upon which to formulate judgment. Consequently, the experiments discussed herein were designed to provide information that would be applicable to certain of these issues.

One of the chief sources of disagreement was the comparative effect of different degrees of leaf and stem damage on yield. Some believed that leaf damage was of little importance in the evaluation of losses and gave primary consideration to injuries to the stems. Others considered both types of damage but disregarded the possible influence of stage of plant development at the time of injury on ability to recover. Although not strictly comparable, an idea of the relative importance of loss of stand and loss of leaf area may be gained from the results of the stand reduction and defoliation tests. In these tests the removal of 50 percent or less of the stand or leaf area before blooming caused little or no reduction in yield. From bloom stage on, however, 50 percent stand reduction at ground level resulted in increasingly greater decreases in yield than 50 percent defoliation. Similar tendencies were observed with 75 percent stand reduction at the same height at all stages of growth. When cut off at one-half the height of the plants, on the other hand, the different percentages of stand reduction caused definitely greater decreases in yield than the comparable percentages of defoliation at the "green bean" stage only. In the light of these results, therefore, one might conclude that both leaf damage and stand removal would merit attention in calculating injuries to soybeans from hail. The extent of losses in yield due to each type of damage, nevertheless, appeared to depend not only upon the amount of injury but also upon the stage of growth when it was inflicted.

Two additional types of injury besides loss of stand and defoliation were encountered in the simulated hail tests where both leaf and stem damage were inflicted simultaneously. One of these, stem bruising, was another factor affecting yield, although its effect was difficult to determine,

especially when minor in extent. The other, pod removal, also has raised similar doubts. Their effects on yield can only be postulated, however, as neither was studied individually.

Judging from the insignificant decreases in yield before and during blooming as a consequence of 25 percent stand reduction, it is rather difficult to imagine that stem bruising *per se* could have any marked effect on yield, at least if inflicted prior to the stage of beginning pod development. Thereafter, as the stems gradually become more woody, the likelihood that bruising would materially damage the stems and affect yields would seem to be even less. It has been noted, however, that severe, deep bruises weaken the stems and provide an avenue of entrance for stem rotting organisms. Plant stems bruised in this manner may eventually break over at the point of the bruise, thereby giving the effect of stand reduction. If this occurred with a large percentage of the plants a marked reduction in yield probably would result. It is very possible, however, that a large loss of leaves, stems and branches would occur if actual hail caused severe bruising. Under such circumstances it would be almost impossible to determine which damage factor was primarily responsible for the losses in yield. At the opposite extreme, it does not appear likely that the small, shallow stem bruises resulting from many of the lighter hailstorms would in themselves have any appreciable effect on yield. It would be desirable, however, to determine the consequences of different degrees of stem bruising at different stages of plant development in a separate study before making any definite conclusions regarding its effect.

Pod removal, like stem bruising, also should be investigated in a separate study. The results obtained in the simulated hail tests provide little direct evidence concerning its effect on yield. The loss of a large percentage of the pods at any stage in their development undoubtedly would lower yields. The effect on yield, however, would be least during the earlier stages of pod development, as the initiation of new flower buds and an increase in size of seed in the remaining pods would partially compensate for the pods lost. It was noted, in both the simulated hail tests and the defoliation tests, that the capacity for new flower bud initiation ended at about the time the pods reached full length (approximately stage 7 as used herein). The compensating effect for loss of pods would therefore diminish rapidly as the pods develop, until at maturity, or shortly before, it would be completely absent. At that time the amount of

yield decrease due to seed loss would be expected to equal the percentage of seed removed, as substantiated by the results in the shatter test.

A factor closely related to pod loss during the early stages of pod development is that of loss of flowers. It has been argued by some that hail may knock off flowers, thereby decreasing the number of pods formed. An understanding of the flowering processes in soybeans would show this supposition to have no basis. Actually, the soybean plant is capable of producing many more flowers than ever develop into pods. When the available supply of food materials in the plant is large due to favorable growing conditions, a relatively large percentage of the flowers may develop into pods. Conversely, when the food supply is limited a poor set of fruit usually results. This phenomenon has been described in detail by Murneek (14). Cartter and Hopper (1) summarized it by saying that "during flowering and early ovule and seed development the soybean plant regulates, by physiological abortion, the number of seed that it can fill under existing environmental conditions." Since the soybean plant flowers over a period of several weeks, it can readily be seen why the loss of a few flowers on any one day would have no effect on the number of pods that eventually develop to maturity.

In the previous paragraph it is intimated that growing conditions exert a considerable influence on pod formation and seed setting in soybeans. Similarly, weather conditions, both preceding and following hail injury, may influence the amount of recovery. Eldredge (4) observed that corn plants completely or two-thirds defoliated just prior to the onset of a severe drouth period in 1930 actually yielded more than undamaged plants. Whether soybeans would respond in such a manner is not known, as soil moisture was ample at all times during these studies. The unpredictable nature of drouth conditions would make it difficult to obtain such information. We believe, however, that either extreme heat and drouth or excessive cold and damp weather just preceding and subsequent to hail injury during the early stages of growth would result in less recovery than in tests reported here, especially if more favorable weather prevailed later, during seed setting. Likewise, excessive rainfall and high humidity at any stage might foster the development of stem and leaf disease organisms at points of injury, the effect of which would be to deplete the supply of food material available for vegetative and reproductive growth. Another possible but more indirect

effect of weather would be damage by frost in the fall due to a delay in maturity resulting from hail injury early in the growing season.

In addition to retarding the recovery of plants damaged by hail during the early stages of growth, unfavorable growing conditions may also aid certain weeds at the expense of the soybeans. This may be due to the fact that such weeds are better adapted to the weather extremes; or, in the case of grassy weeds, they may be damaged less by hail. It is more probable, however, that weed growth flourishes because of lessened competition from the damaged soybean plants and in case of wet weather, as a result of the inability to cultivate for weed control. This then brings up the argument commonly heard that hail injury greatly increases weed growth in farmers' fields even when ideal conditions for recovery prevail. Although this is partly true, as noted in the non-weeded simulated hail test in 1946, much of the added weed growth in hail-damaged fields is due to the failure to carry out normal cultivation practices following damage. We recommend that soybean fields not excessively damaged by hail be cultivated to control weeds as soon as possible after the hailstorm. This practice was followed in the non-weeded test in 1946. Increased weed growth over that of undamaged plots occurred only following heavy damage inflicted when the plants were 4 to 5 inches tall. The field in which this test was conducted, however, was kept relatively free of weeds from the beginning. Fields in which weeds are prevalent before hail injury occurs, on the other hand, are much more liable to show increased weed growth as a consequence of hail than fields relatively free of weeds before the time of damage.

The last factor selected for discussion is that of varietal differences in response to hail injury. Since soybean varieties vary widely in their manner of growth, it would seem logical to assume that they all may not be similarly affected by comparable degrees of injury. In order to obtain information pertinent to this matter two varieties, namely, Richland and Lincoln, were compared in the 1944 test. These two varieties were selected because of their differences in growth habit: Richland is of the non-branching type and very lodging resistant, while Lincoln is of the branching type and much less resistant to lodging. The results, however, indicated that their reaction to the different degrees of damage was very similar. Unless further investigation proves otherwise, it appears that varietal diferences in response to hail injury would be a relatively in-

significant factor in the estimation of hail losses to soybeans.

Thus far attention has been centered primarily on the effects of injury to soybean yields. The effects of injury on other characters should not be overlooked, as they also may indirectly affect the over-all production from an economic standpoint. As an example: The delay in maturity brought about by heavy damage during the early stages of growth may result in lower yields and poorer quality seed in the event of early frosts in the fall. In another case, the marked decreases in plant height as a consequence of severe injury during the blooming period might increase harvesting difficulties, by making pods on basal portions of the plants more inaccessible to the combine. The increased lodging which generally results from most hailstorms would have a similar detrimental effect upon harvesting operations. In addition, damage during the period of seed development may result not only in poorer seed quality but also in lower oil content of the seed. This result would tend to be reflected in lower market prices for the beans, especially if the beans were marketed on the basis of their oil content. Although still other examples could be cited, these should suffice to indicate that the effects of injury on agronomic characters other than yield, and possibly on chemical composition of the seed, would certainly deserve some consideration in hail loss evaluations.

Although these experiments were conducted mainly to gain information in regard to hail injury, certain features of the results may be applicable also to the approximation of injuries received from other production hazards common to soybeans in various parts of the United States. The results obtained in the defoliation tests, for example, provide clues as to the relative significance of leaf damage at various stages during the season from frost, insects, rabbits and leaf diseases. It is not uncommon for light frosts to partially kill young soybean plants soon after emergence. The results from stage 1 in the defoliation tests indicate that if not over 75 percent of the leaf area were killed by frost the plants would recover without any noticeable effect on yield. Likewise, the destruction of various amounts of leaf area by insects such as grasshoppers, blister beetles or the velvet bean caterpillar or by leaf diseases should have an effect quite comparable to that observed in the defoliation tests. An attack by grasshoppers or other of the leaf-eating insects during pod formation and early seed development probably would have a more disastrous effect on yield than if it occurred either earlier or later. Considering their

possible toxic effects, leaf disease organisms may cause much larger reductions in yield than commonly supposed, especially if they infect the plants during the reproductive period.

Results of the stand reduction tests may be applied to cultivation practices with soybeans. Many farmers decline to use the rotary hoe, spike-tooth harrow or weeder on small soybeans because of the supposed danger of damage to or breakage of the plants. Judging from the insignificant decreases in yield that resulted from 25 or even 50 percent stand reduction when the plants were 4 to 5 inches tall, it is obvious that there is not much danger in using the above mentioned cultivating equipment for weed control in soybeans. In fact, it is more likely that yields would be increased rather than decreased by their use, because of more effective control of weeds.

Detailed physiological explanations have been omitted from this discussion, primarily because we believe they would have offered little information pertaining to the objectives of the investigations. Instead, an attempt has been made to discuss the results in the light of their possible relationship to actual hail injury and the problems that accompany it. Although the scope of the experiments was necessarily limited, considerable information concerning the effects of leaf and stem damage to soybeans was obtained. It would be advantageous to investigate much more thoroughly the effects of stem bruising, pod removal and drouth conditions on yield and on other characters. Additional research regarding the alteration in chemical composition of the seed by injury would also be desirable.

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